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Asymptotic models and curved surfaces : application to railway transportation

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Abstract

Several wireless communication systems are developed for communication needs between train and ground or between trains in the railway or mass transit domains. In order to deploy these systems in specific environments, such as tunnels, straight or curved, rectangular or arch-shaped section, specific propagation models have to be developed. In this paper, we propose a method to model the radiowave propagation in straight arch-shaped tunnels by using asymptotic methods, such as ray tracing and ray launching, combined with the tessellation of the arched section. A method of interpolation of the facets normals is implemented in order to minimize the error made when using the tessellation. These results are compared to those found in the literature in order to validate our approach.

1 Introduction

Wireless communication systems are more and more used in guided transports domain (mass transit, train ...) for train to ground or train to train communication applications. These systems are developed to satisfy operational needs, for security and comfort (control-command or information). They are usually deployed in complex radioelectrical environments such as tunnels. High field levels are often required to guarantee a safety systems behavior and needed applications QoS. The deployment in tunnels is nowadays treated by intensive measurement campaigns, long and expensive, and so have to be specifically analyze. The development of simulation tools for the radioelectrical planification in these contexts is so relevant. However, classical methods like ray tracing did not function any more for curved and/or arch-shaped tunnels [1, 2, 3, 4, 5].

This paper presents obtained results for different propagation models in straight tunnels of arch-shaped section considering a tessellation of the vault to approximate the curvature. In section 2, we give obtained results with ray tracing technic using image method. The limitations of this method in the considered configurations are explained. Section 3 details the results provided by a classical ray launching technic, using the facets' geometrical normals. To eliminate the errors introducing by this method, we propose to interpolate the facets' normals according to an image synthesis technic [6]. Thus, a significant results improvement is noticed. Finally, conclusions and perspectives of this work are given.

2 Tessellation associated to ray tracing

Models based on ray tracing are frequency asymptotic methods which consist in a direct and exhaustive search of geometrical paths followed by the waves, between a transceiver and a receiver. This technic is based on the image method which lies on the computation of all transceiver's images according to the environment facets and a given number of successive reflections. The images are computed by axial symmetry according to each facet, the normal of the facet is so

very important in the paths search step. In the case of a curved surface, which can be approximated by an infinity of tiny facets, a single facet generates an infinity of images (because of an infinity of normals). As in [3, 4, 5, 7], we propose to approximate the curved surface by a reasonable number of plane surfaces, to limit the computation time which is directly connected to the number of scatterers.

All the results are given in terms of received power (P_r) normalized by the radiated power (P_t) according to the distance between transceiver and receiver along the longitudinal tunnel axis. Simulations have been conducted at the 1 GHz frequency in a straight tunnel of arch-shaped section, in the configuration of figure 1.

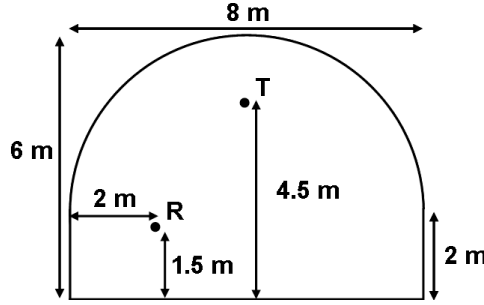


Figure 1: Configuration of simulation

The transceiver is located at the center of the vault, at a height of 4.5 m, whereas the receiver is from 2 m of the tunnel's left side wall, at a height of 1.5 m, and moves along the tunnel. The obtained results according to the number of facets are given on the figure 2 (a).

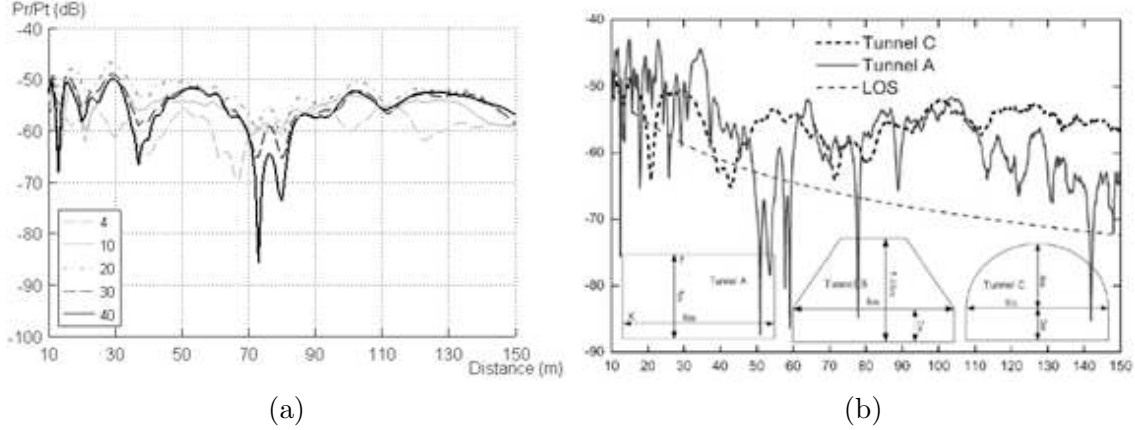


Figure 2: Results of (a) our ray tracing according to the number of facets, (b) Wang & Yang [2]

As we have shown in [7] by comparison with measurement, it appears that for a reasonable number of facets, the received power does not converge. This is explained by the fact that each supplementary facet introduces new paths and so modifies the received power. A convergence of the look of the curve presented in figure 2 (a) will be attempt for a great number of very tiny facets. Indeed, the new paths introduced by each new facet will be quasi identical to the previous ones and so will engender a simple offset on the received signal level. These new paths are so doubletons of a real path, provoquing so a misestimation of the received power. However, because of the direct and exponential link between the facets number and the computation time of ray tracing, it is impossible to verify this remark by simulation. In all the cases, the ray tracing

algorithm shows here its limitations. The results obtained by Wang & Yang [2] illustrated on figure 2 (b) confirm this observation. In the next section, we present a ray launching method allowing to solve this problem.

3 Tessellation associated to ray launching

The ray launching technic [8] consists in launching in the environment a great number of rays from the tranceiver. These ones propagate by successive reflections. It is then necessary to determine the rays reaching the ponctual receiver. To do this, one considers a sphere around the receiver, and each ray intersecting this sphere is so considered as contributing to the received power. Thus, several rays geometrically closed may be retained while they correspond to only one path in the Geometrical Optic meaning, falsifying thus the received power estimation, as for the ray tracing (*cf.* section 2). In this case, one talks about multiple rays. To guarantee the power convergence consists so in identifying these multiple rays and to retain only one of them in the received power computation. The difficulty and the accuracy of this method are based on the regulation of the sphere size and Identification of Multiple Rays criteria (IMR) [8].

The retained IMR algorithm consists in successively evaluating the above criteria :

1. the number of reflection : if the reflection number of two rays is the same, then we evaluate the second criterion,
2. the length of the ray : the lengths (or propagation delays) of the two rays are compared. If the difference is lower than a predefined threshold, we evaluate the last criterion,
3. the direction of departure : the emission angles of the two rays are compared. If the angle formed by these ones is lower than a predefined threshold, then the two rays are considered as multiple, and only the first one is retained.

If the first criterion is unambiguous, the two next ones need threshold values which have to be adequately fixed to guarantee the power convergence. This last point is the main difficulty in the implementation of our ray launching algorithm.

3.1 Facets normals use

In this section, the results are obtained from our implemented ray launching method (with reception sphere and IMR) associated to the consideration of the facets' normals for the computation of the rays direction after reflection.

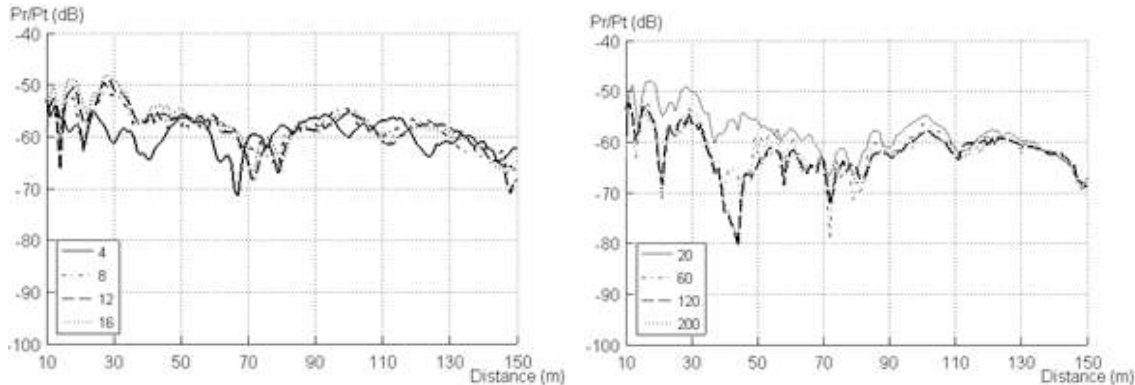


Figure 3: Ray-launching results according to the number of facets

Figure 3 presents the results at 1 GHz according to the used facets number. Thanks to the IMR algorithm, a results convergence is observed for a high number of facets (about 120).

Furthermore, this result is very close to the one proposed by Wang & Yang [2], which validates this approach.

3.2 Facets' normals interpolation

The tessellation of the tunnel arch-shaped section drives to an error on the normals at the reflection points. Indeed, whatever the reflection point is, its associated normal is systematically the one of the corresponding facet, as illustrated on figure 4 (a).

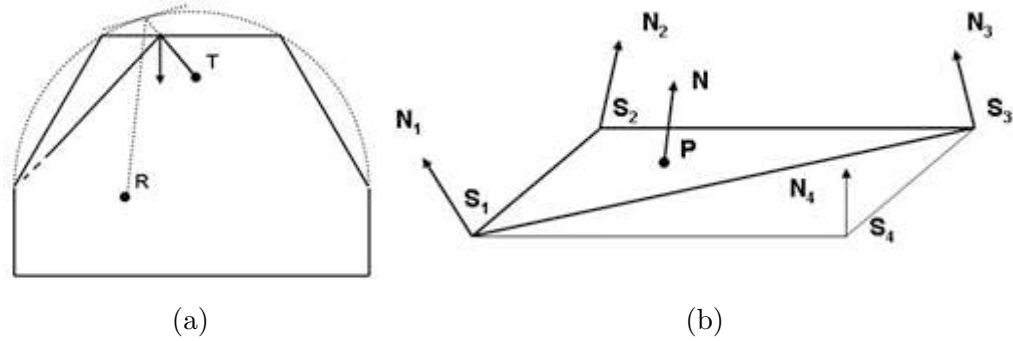


Figure 4: (a) Tessellation and error made on the normals, (b) normals interpolation method

This example shows that the use of the facet's normal drives the ray to go away from the receiver and so to its elimination, while in reality, the vault's normal at the reflection point drives the ray to intersect the reception sphere, proving its existence according to the geometrical optic meaning. The reverse of this example driving to retain paths having no real existence is also true.

Consequently, we present here a method allowing to minimize these errors by estimating the curved surface's (the vault) normal at the reflection point. This estimation consists in a linear interpolation of the facets' normals based on the Phong algorithm [6], well known in image synthesis.

The principle is, for each facet, to compute the normal of each of the four facet's edges. The edge's normal is stated as the mean of the adjacent facets' normals if the angle between the facets is sufficiently weak. The N normal interpolated at the reflection point P of a facet F is based on the barycentric coordinates of P in the triangle $S_1S_2S_3$, as it is illustrated on figure 4 (b).

The figure 5 presents the obtained results according to the normals interpolation method for the configuration of figure 1.

One more time, a convergence of results to the Wang & Yang [2] ones is clearly observed with the facets number increase.

Nevertheless, the normal interpolation at reflection points allows to obtain this convergence very faster. Indeed, 16 facets are sufficient in this case while 120 are needed without interpolation.

4 Conclusion

This article presents obtained results using different methods allowing to model the radio wave propagation in straight tunnels of arch-shaped section.

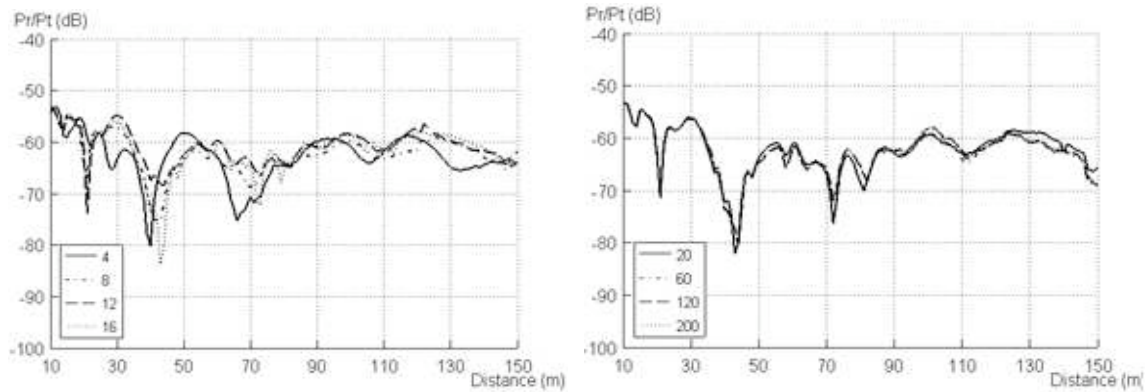


Figure 5: Ray launching results with normals interpolation according to the number of facets

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